The Cosmic Microwave Background Radiation and its Polarization

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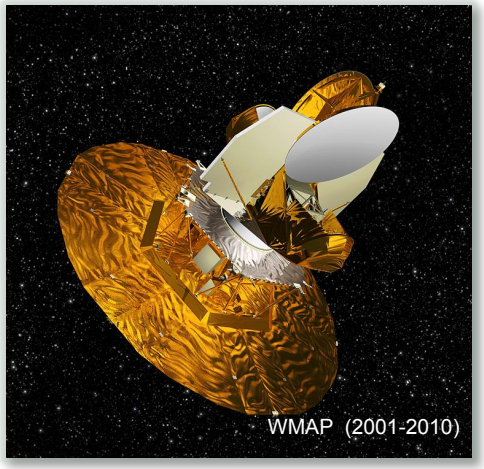
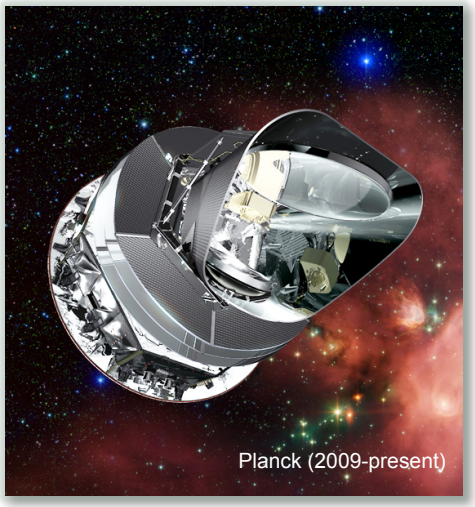
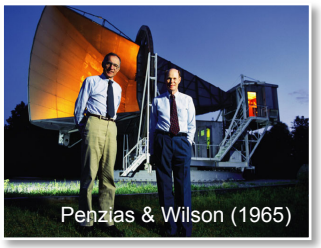
CMB: Past and Present…





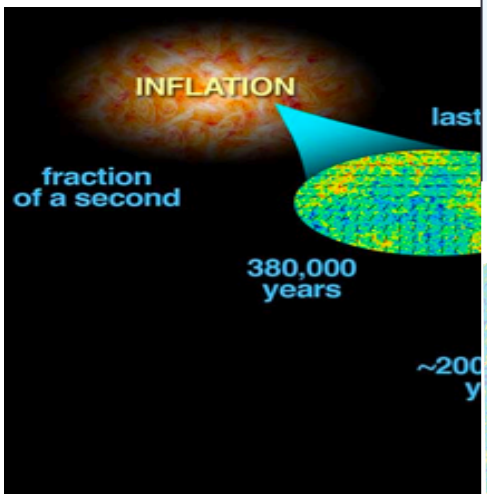


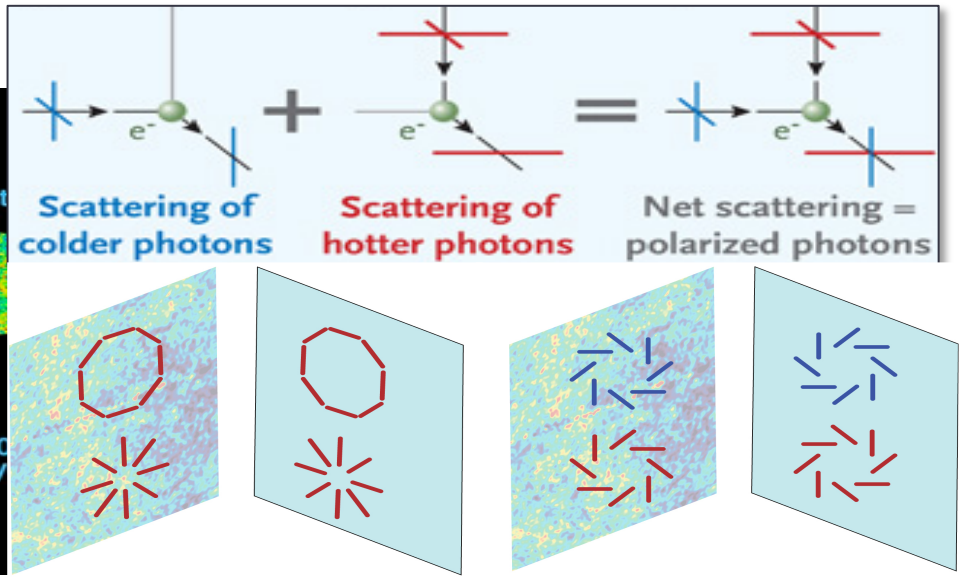
Cosmic Microwave Background:
Polarization Anisotropies

Inflation Paradigm:
Quantum fluctuations in the metric and inflaton expand to astronomical scales.

Scalar perturbations
create density perturbations.

Tensor perturbations
create gravity waves that propagate from early to late times.

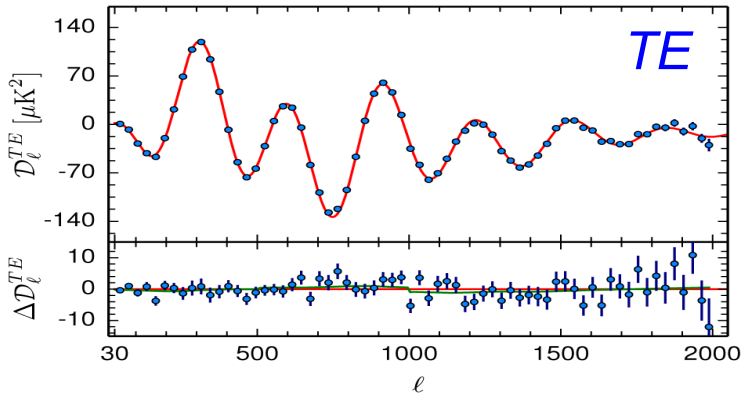


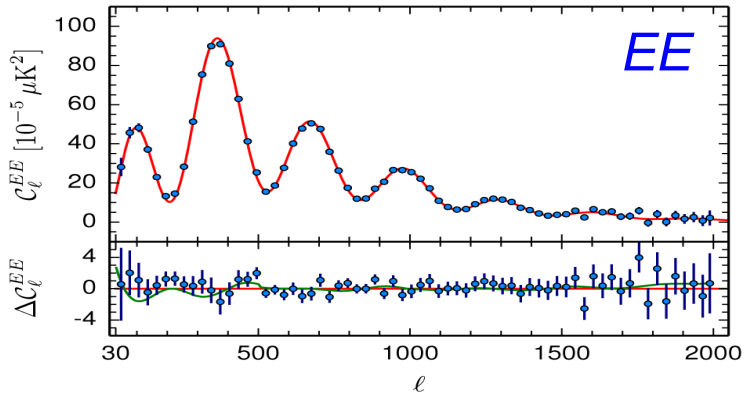


Comic Microwave Background:
Thomson scattering ➞ CMB Polarization
- Density perturbations (scalar) – *E mode only*
- Gravity waves (tensor) – *E and B modes*

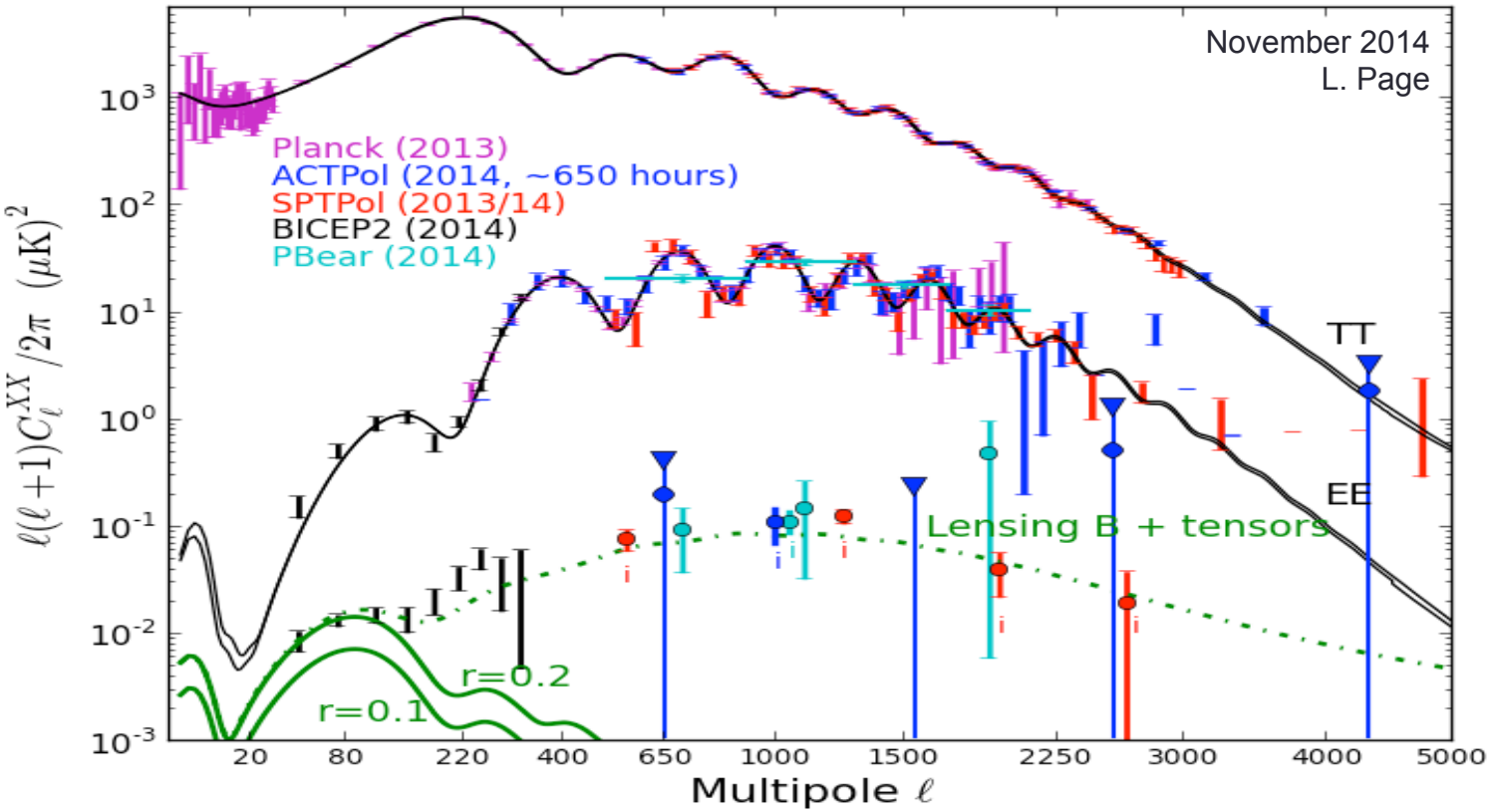
CMB Status: Temperature & Polarization

- Planck – full sky maps with 4’ resolution available…
- Rich cosmological and galactic data sets…
- Consistency with 6 parameter cosmological model…
- Consistency among numerous experiments…

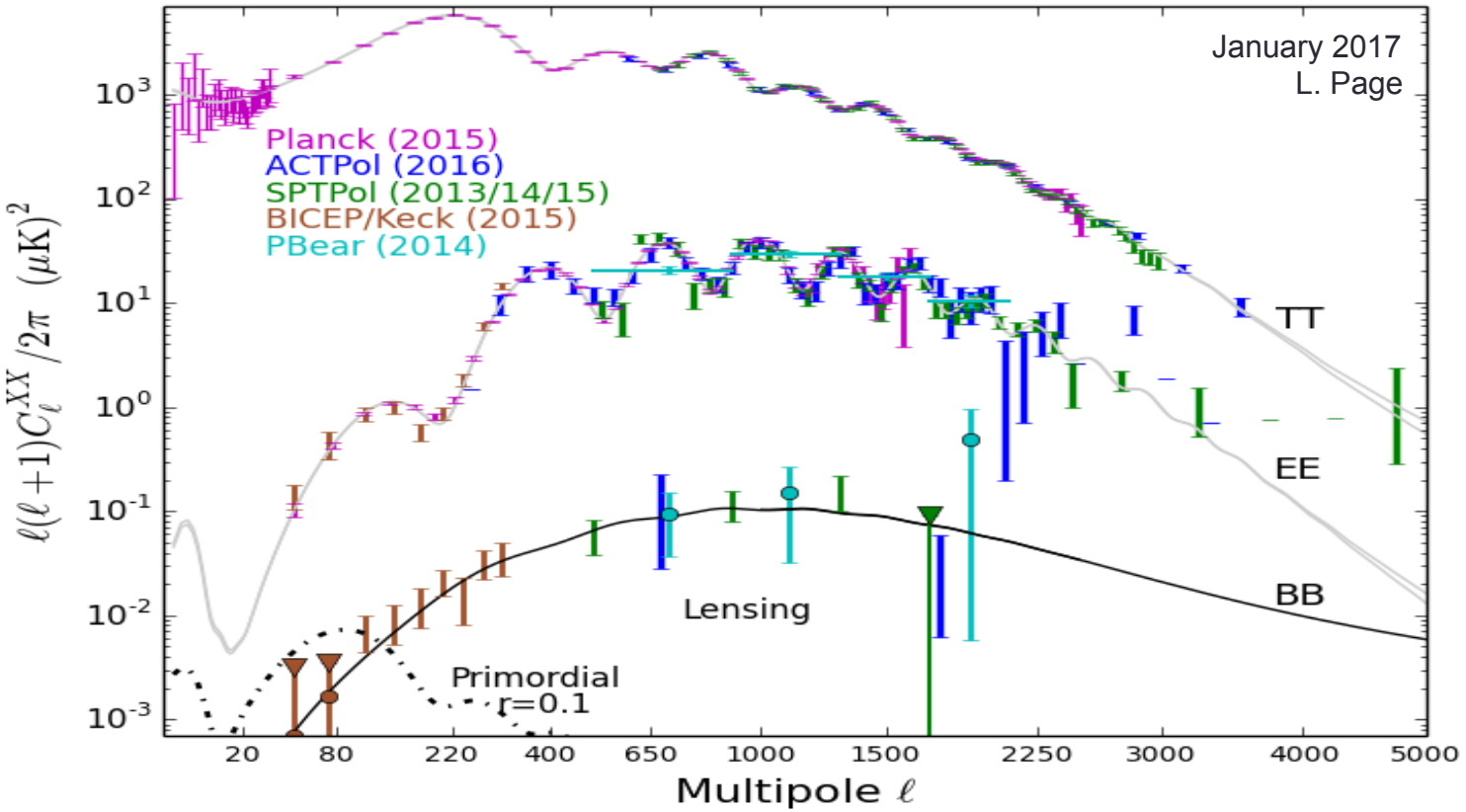




CMB Status: Temperature & Polarization



CMB Status: Temperature & Polarization



CMB Status: Temperature & Polarization

- Temperature power spectra characterized over ~ four decades by a variety of experiments…
- No surprises with *E*-mode power spectra…
- Indirect detections of *B*-mode via lensing…
- Joint BICEP2/Keck analysis with Planck data yields
  r = 0.028 +/- 0.026 and r < 0.09 at 95% confidence

P.A.R. Ade et al., “Joint Analysis of BICEP2/Keck Array and Planck Data” PRL (2015) 114, 101301.

P.A.R. Ade et al., “Improved Constraints on Cosmology and Foregrounds from BICEP2 and Keck Array Cosmic Microwave Background Data with Inclusion of 95 GHz Band” (2016) Phys. Rev. Lett. 116, 031302

CMB Coming Soon...

Analyzing available Polarization Data:

- Planck (space, intermediate ell)
- BICEP2/BICEP3/Keck (ground, low ell)
- SPTPol (ground, high ell)
- ACTPol (ground, high ell)
- POLARBEAR (ground, high ell)
- ABS (ground, low ell)
- EBEX (balloon, intermediate ell)
- SPIDER (balloon, low ell)

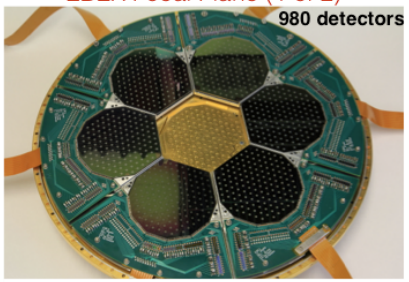
Launch/Deployment

- PIPER (balloon, low ell)
- CLASS (ground, low ell)

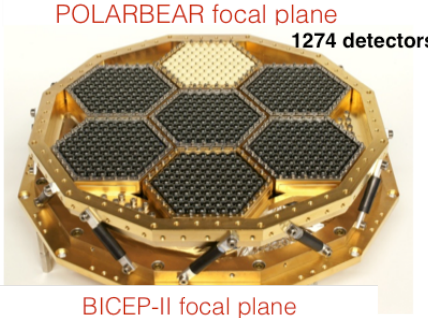
Funded extensions to ~20,000 detectors

- SPT3G, Advanced ACTPol, Simons Array

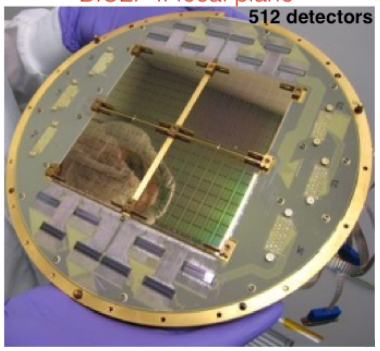
EBEX Focal Plane (1 of 2)



POLARBEAR focal plane

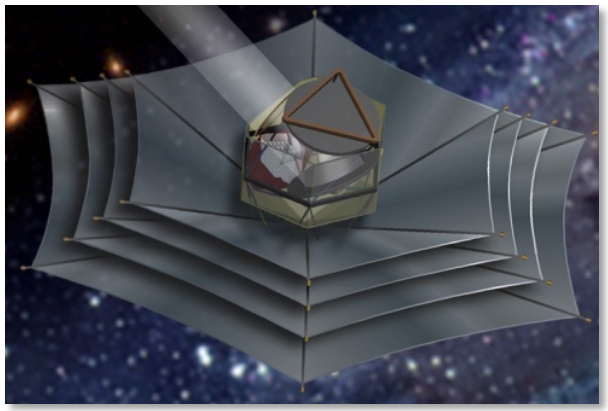


BICEP-II focal plane



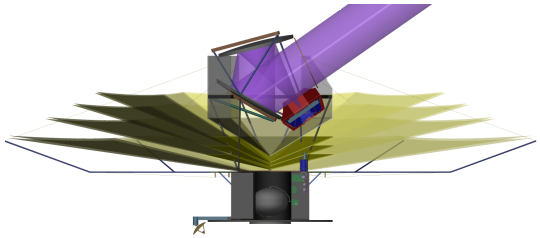
CMB Polarization Mission Planning

- NASA Inflation Probe to provide high-sensitivity measurements over entire sky enabling extraction of all cosmological information from CMB in polarization.
- B-mode polarization tests the physics behind the process of inflation plus tests of neutrino mass, mapping large-scale structure with gravitational lensing, and epoch of reionization science.
- Space provides access to the *largest spatial angular scales* and *entire spectral range* of interest – a combination of capabilities which far surpasses that achievable from other observational platforms.



Inflation Probe Mission Landscape

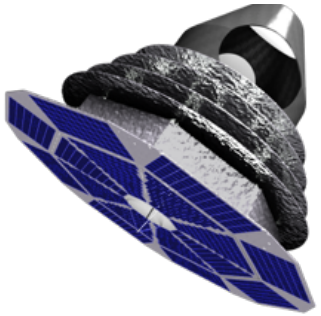
EPIC-IM



NASA

- Probe-Scale Mission Study: $400M - $1000M
  - Proposal submitted (11/2016) – awaiting NASA response
  - Part of NASA preparations for 2020 Decadal Panel
  - Single proposal representing entire CMB community
  - Science: *Inflation/Quantum Gravity, Particle Physics, Dark matter, Dark energy, Galactic Astrophysics*
- PIXIE - submitted as Explorer class mission (2016)
  - Low Resolution (~1.6 deg@150GHz), LEO, FTS
  - Science*: Inflation, Spectral Distortions, Galactic*

COrE+



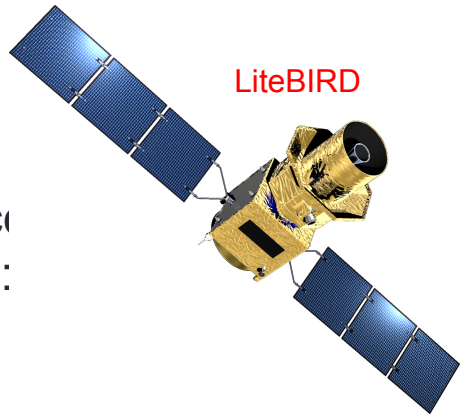
ESA M5, COrE+

- Submitted in 10/2016; Response expected in Spring 2017; Launch = 2028
- E550M ESA + E50-100M Members = E600-650M
- Medium resolution (5.5 arcmin @150 GHz), L2
- Intense European interest for US contribution; Strong community backing
- Science*: Inflation, Lensing/Clusters, Neutrinos, Galactic*

Inflation Probe Mission Landscape

JAXA, LiteBIRD

- Low Angular Resolution
- Includes US contribution (Focal Plane)
- Phase A studies funded in Japan (conclusion in 2017, SRR early 2018) and in the US (concluded in summer 2016 – awaiting NASA decision)
- Launch (if approved): 2025+
- Science: *Inflation, Galactic*



ESA/JAXA Collaboration

Discussions ongoing between ESA/JAXA and scienc teams regarding possible collaboration as part of M5: Main discussion point is targeted angular resolution

CMB Community Meetings and Inputs

- Probe-Scale Mission Study proposal submitted
  - Part of NASA preparations for 2020 Decadal Panel
  - Single proposal representing entire CMB community
  - Complementarity of Inflation Probe and CMB-S4 science as well as measurement foreground challenges to be studied
- AAS Special Session, "The Polarization of the Cosmic Microwave Background", San Diego, June 15, 2016.
- Workshop Series, "Cosmology with CMB-S4":
  - Lawrence Berkeley National Laboratory, March 7-8, 2016
  - University of Chicago, September 19-20, 2016
  - SLAC, February 27-28, 2017 → *save the date*

Inflation Probe Science Interest Group:

- Goal: Develop a US community response which articulates a consensus for a Inflation Probe mission priorities. Inputs from all members of the community are welcomed.

- Inflation Probe SIG website and mailing list:
  http://pcos.gsfc.nasa.gov/sigs/ipsig.php
  http://pcos.gsfc.nasa.gov/sags/ipsag/ipsag-maillist.php

- Physics of the Cosmos Program Analysis Group (PhysPAG) Inflation Probe Science Interest Group (IPSIG) Community Representatives: Amber Miller & Edward Wollack